Surf Zone and Very Shallow Water Communications Modeling: SIO Component

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Award Number: N000140010303

LONG-TERM GOAL

The long-term goal of this research is to develop predictive models of acoustic modem performance in the surf zone given a minimal set of environmental inputs.

OBJECTIVES

The immediate objectives are to (1) develop a deterministic model for acoustic propagation through the surf zone that accounts for a real surface wave field and wave-induced bubble clouds and (2) a signal-to-noise ratio model for acoustic telemetry signals in the surf zone.

APPROACH

The SIO component of this multi-institutional effort consisted of five sub-tasks. The first two of these were to establish the definition and coding of the deterministic acoustic model and reconcile the model with field data. These two tasks comprised the major part of the effort and were done in collaboration with Dr. Chris Tindle at the Auckland University Physics Department, New Zealand. The remaining three tasks were to analyze acoustic transmission data through wave-induced bubble clouds, incorporate the results of this analysis into the deterministic acoustic model, and develop a signal-to-noise ratio model for acoustic telemetry signals.

WORK COMPLETED

The first two tasks of this project relating to the development and verification of the deterministic model are essentially complete. The model is based on conventional ray tracing but follows wavefronts directly and uses the wavefronts themselves to determine the expected acoustic field. This new method of modeling underwater sound propagation is called Wavefront Modeling, and has been adapted from deep water to include the effects of a sloping, penetrable ocean bottom and ocean surface with unbroken ocean waves. When the first surf zone simulations were run with this model using field measurements of shoaling surf, the existance of sound caustics in the surf zone were predicted. The shoaling gravity waves act like focussing mirrors, causing transient focal regions that move through the surf zone as the wave move shoreward. The discovery of these caustics was followed up with a short-term surf zone experiment in November of 2000 (the Wavefronts experiment), which was optimized to verify their existance and characterize their properties. The results of this experiment are described in the next section.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2001**	2. REPORT TYPE	3. DATES COVERED **00-00-2001 to 00-00-2001**

4. TITLE AND SUBTITLE **Surf Zone and Very Shallow Water Communications Modeling: SIO Component**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Marine Physical Laboratory,,Scripps Institution of Oceanography,,La Jolla,,CA, 92093**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The long-term goal of this research is to develop predictive models of acoustic modem performance in the surf zone given a minimal set of environmental inputs.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT	b ABSTRACT	c THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**6**	

The next phase of the determinstic model development is to include the absorbing properties of bubble clouds in the wavefronts model. The model can accommodate bubble cloud absorption effects in its present form, and will be compared with transmission data that includes bubble clouds in late October this year. In order to accommodate absorption by bubble clouds, field measurements of scattering and absorption by surf-induced bubble plumes is required. Data from two experiments, the first conducted in 1996 at Red Beach as part of the Adaptive Beach Monitoring Program and a second in 2000 off Scripps Pier as part of this program, is available and partially analyzed. The signal-to-noise ratio model will be established using the wavefronts model once complete.

An important aspect of this proposal was to transition the components of scientific models developed within this program to PCSWAT, developed and maintained by Dr. Gary Sammelmann at the Coastal Systems Station, Panama City, Florida. The surface gravity wave and transmission data sets from the Wavefronts experiment were used to verify the capability of PCSWAT to model deterministic waves on the ocean surface. In addition, the key physical components of a bubble advection/diffusion model developed by Svein Vagle and David Farmer at the Institute of Ocean Sciences, BC, have been coded into PCSWAT.

The final phase of the modeling, which is to determine the minimal set of environmental parameters that are required to predict modem bit rates for a specified bit error rate, is being done in collaboration with Dr’s Kerry Commander and Robert McDonald at CSS and Dr. Jim Preisig at WHOI, and will be complete by the end of the program period (December 2001).

RESULTS

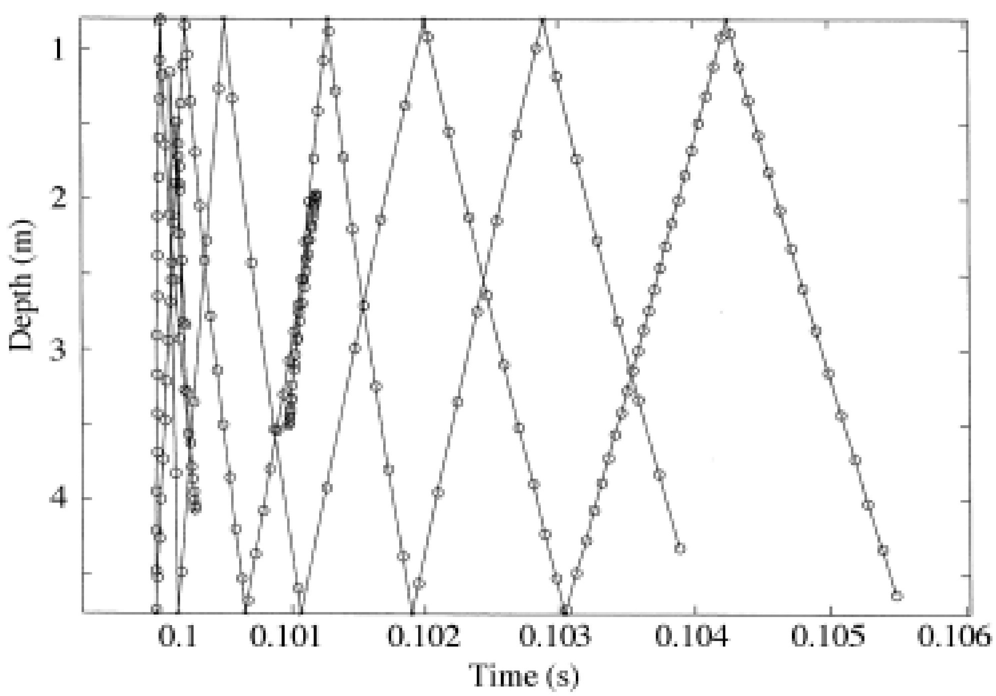

Figure 1. A depth-time diagram created with the wavefronts model. The figure shows wavefront arrivals plotted versus depth and time, 150 m from a source in 5 m of water with a shoaling surface gravity wave train. The folded wavefront at about 1.01 s extending from 2 to 4 m is a high-intensity region of focused sound reflected from the ocean surface.

A typical depth-time diagram plotted using the wavefronts model is shown in Figure 1. The diagram is used to find both the arrival time of pulses and their amplitude in order to predict the signal that would be observed on a hydrophone. Figure 2 shows a comparison between the model predictions and data taken during the Wavefronts experiment. A pressure array was deployed along the transmission path to provide estimates of the surface elevation synchronized with single-cycle pulse transmissions centered on 10kHz. The gradual decay in amplitude seen in the late arrivals is due to seafloor absorption, which is not included in the model prediction shown. Caustic formation can be clearly seen in the surface-reflected pulse arrival structure, and the pulse amplitude and delay are accurately reproduced by the model. The implications of these transient, focused arrivals for underwater communications and buried object detection is an ongoing enquiry.

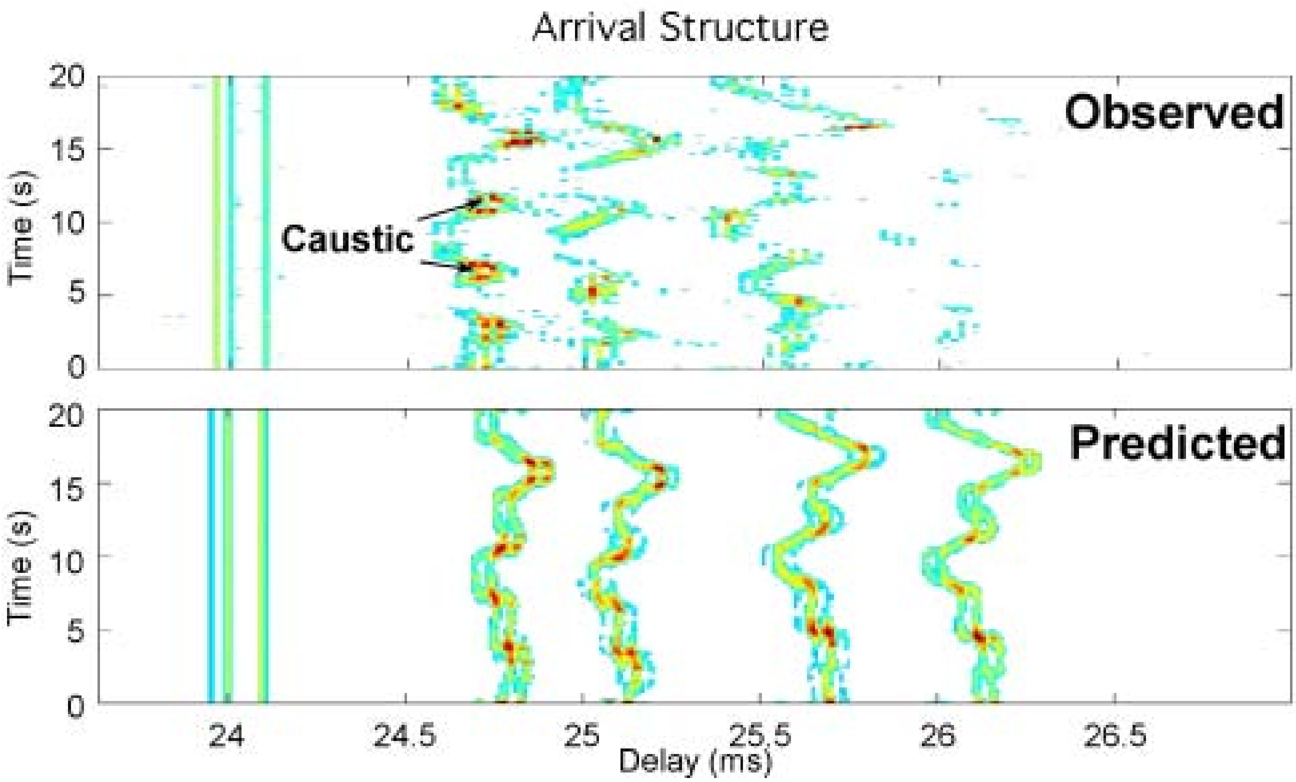

Figure 2. These two plots show the observed and predicted arrival structure for single cycle pulses transmitted over 40 m beneath shoaling surf in 5 m deep water. The top plot shows successive pulses stacked vertically, emphasising changes in the arrival structure over time. The three vertical bands at 24 ms are the direct and bottom-reflected path arrivals. The wavy vertical band at 24.8 ms is the surface reflected arrival. Systematic variations in both pulse arrival time and amplitude can be seen. The red dots labeled 'caustic' in the plot are high-intensity, focal regions created by surface reflections. The bottom plot shows the arrival structure predicted by the wavefronts model calculated using the actual surface gravity wave field recorded by a pressure array during the transmission experiment. The next phase of the modeling is to include the effects of bubble cloud absorption in surf zone telemetry transmissions. In its present form, the wavefronts model can accommodate absorption by bubbles clouds with minor modifications.

Transmission data including the effects of controlled bubble injection were taken during the Wavefronts experiment and a comparision between this data and model predictions will be completed during October, 2001. In order to model the effects of wave-induced bubble plumes, it is necessary to have measurements of their acoustical properties. A plot of the sound speed and absorption immediately beneath breaking surf is shown in Figure 3. The data from the plume transmission experiment completed this year is still under analysis, and will be used to supplement the existing data set. The data that has been analyzed shows large reductions in sound speed and high levels of scattering and absorption immediately after a wave breaks. These results reinforce the idea that, to first order, the effects of bubble plumes can be modeled by removing wavefronts paths that intersect plumes from the pulse arrival structure.

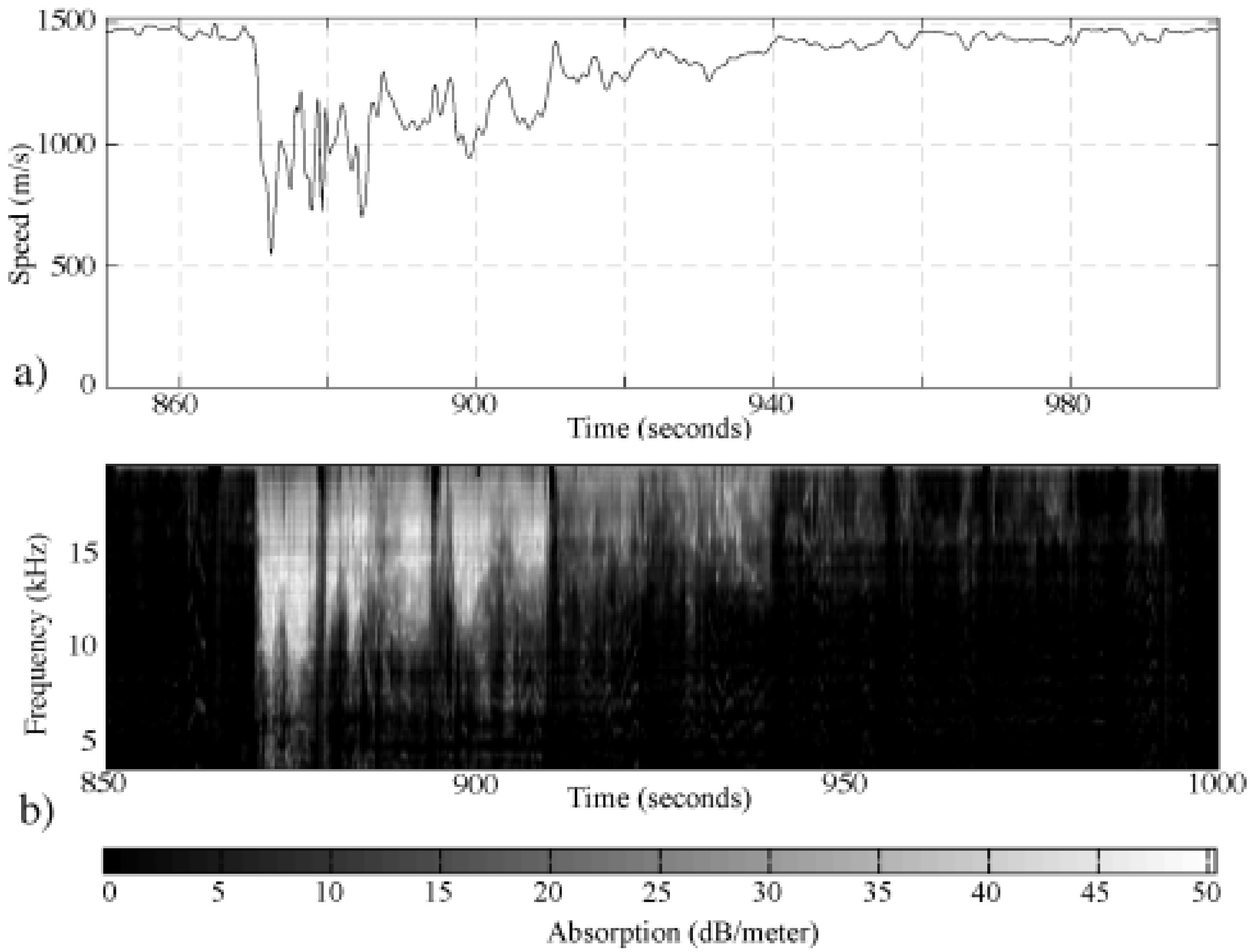

Figure 3. These two figures show the acoustical properties of bubble clouds measured over a 30 cm propagation path beneath breaking surf with a travel time sonar. The top plot shows the sound speed estimated over a 5 kHz band centered on 10 kHz as a function of time. The sudden reduction in sound speed from 1500 m/s to 800 m/s at about 870 s is due to a wave breaking over the travel time sonar.

The gradual recovery in sound speed seen over the following 100 s occurs as bubbles diffuse away and are lost to the water column through dissolution and degassing. The bottom plot shows acoustic absorption plotted versus frequency and time in units of dB/meter. Strong absorption persists at communications frequencies for up to 100 s after the initial brekaing wave event.

IMPACT/APPLICATION

The discovery of high intensity sound regions, or caustics, associated with surface wave focusing has implications for underwater acoustic model performance. The impact of these transient, high intensity arrivals on the performance of modem front-end equalizers is currently being studied by Dr. Jim Preisig at WHOI. It is also possible that these focal regions could be exploited to improve buried object detection in the surf zone.

TRANSITIONS

The results of the wavefront modeling have been incorporated into PCSWAT.

PUBLICATIONS

Farmer, D.M., Deane G.B., and Vagle, S. “The influence of bubble clouds on acoustic propagation in the surf zone,” IEEE J. Oceanic Eng., 26 p. 113-124 (2001)

Vagle, S., Farmer, D.M. and Deane, G.B., “Bubble transport in rip currents,” J. Geophys. Res. 106 p. 11677-11689 (2001).